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RESEARCH ARTICLE

A short review on studies on work productivity of mechanical tree planting

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Abstract

Reforestation can be carried out using natural regeneration or artificial regeneration. There are various methods for the artificial regeneration, including manual planting, mechanical planting and aerial/ or ground seeding. This article aimed to review the current reports on the productivity of mechanical planting to provide a summary of productivity rates for the planting machines. According to the review's results, mechanical planting productivity may vary from 143 to 475 seedlings per productive machine hours depending on the machine type, environment (such as surfaces obstacles and stoniness) and the operator experience. Employing skilled operators and selecting suitable worksites can help increasing the work productivity. Integrating and optimising the whole planting chain, from the nursery to the planting phase, can assist also with reducing the cost and improving the productivity. As mechanical planting machines get more widely adopted in different countries, their overall efficiency will improve over time.

Keywords

Planting, Mechanical planter, Work productivity, Seedling, Product machine hours

Introduction

Reforestation includes all activities related to planting and establishment of new forest stands in a specific site. Reforestation can be based on natural regeneration or artificial regeneration. There are various methods for artificial regeneration including manual planting, mechanical planting and aerial/ or ground seeding (https://www.

nrs.fs.fed.us/fmg/nfmg/docs/mn/Reforestation.pdf). According to the United States Department of Agriculture, Forest Service (https://www.fs.fed.us), planting trees with machines can be more efficient than manual planting. It can also result in higher survival rate with up to 13% (https://www.fs.fed.us). Mechanical planting can be ten times more productive than manual planting (https://www.fs.fed.us). When sites are well prepared, the mechanical planters can yield a productivity of 5000 seedlings per hour. Mechanical planting machines are restricted to ground slope of less than 20% (https://www.fs.fed.us). If there are obstacles on the ground such as rocks, rough surfaces and uncleared terrains, then mechanical planting might be less efficient and damages to machines might increase. Other factor influencing the efficiency is the moisture content of the soil. When the soil is very wet, the machines cannot operate safely and effectively due to potential slippage and difficulty in movement. When it is very dry, the seedling survival rate might diminish. There are three types of planting machines: bareroot planters, continuous furrow planters and intermittent planters. Bareroot planters are commonly used machines, however, container seedlings can result in higher survival rate due to their better shape. There are several types of continuous furrow planters, which mainly include the ploughing machines that create a furrow where seedlings can be established. A single hole or short furrow can be created by the intermittent planting machines (https://www.fs.fed.us). To minimise the soil compaction and disturbance, machines such as excavators with a brush blade can be applied for site preparation prior to planting. To reduce the soil compaction, it is recommended to avoid using heavy equipment (Rose and Haase, 2006).

Materials and methods

Work productivity for mechanical planting

According to Lideskog (2018), there is need of further improvement of the productivity of planting during the reforestation phase (Rantala et al. 2009) and it is required to utilise the mechanised planting more widely in order to reduce the costs and increase the productivity (Nilsson et al. 2010).

There is long history of productivity studies in forestry, which mainly have focused on labour productivity or man-machine productivity to help increasing work design, performance and continual work productivity improvement (Heinimann, 2021). Productivity is a ratio of some measure of output to some measure of input uses (Griliches, 1998 cited in Heinimann, 2021). In a simple work study, researchers may focus on mass output and time input. Productivity may be influenced by several factors, such as the operator's skills, work methods/ techniques, technology type and environmental conditions. Work time can be measured using plot level, work shift level, work cycle or elemental level (Magagnotti et al. 2012). Time study results can help the forest planners scheduling the production, budgeting and comparing different procedures and equipment (Murphy, 2005).

This article aimed to review the current study reports on the productivity of mechanical planting and to provide a summary of productivity rates for different planting machines. The available literature was obtained through online journal papers and technical reports published in English by searching electronic databases including Google Scholar, Scopus and Web of Science Google. The keywords used in the search included "planting", "mechanical planting", "planting machines", "productivity" and "time study". The reviewed reports were classified into three main groups based on the geographical regions (including Europe, America and other regions) which are presented in the results.

Results

One of the early reports by the Food and Agriculture Organisation (FAO) in 1978 indicated that mechanised planting can provide a daily productivity of 12000 plants and more per machine. The planting machines can be economically used over large areas with less vegetation density and flat areas with less physical obstacles (FAO, 1978). Two main types on planting machines include tractor mounted or towed by a tractor. The mounted planters are heavier but more productive in difficult and steep terrains.

Europe

Rantala et al. (2009) report that the number of mechanical planting machines have increased in Finland (and generally in Nordic countries). The most common machines are the Swedish Bracke and Finnish M-planter. Rantala et al. 2009 described the M-planter (Figure 1) that has two parallel mounding blades to create the spot mounds where seedlings will be placed. The M-planters have the capacity of 242 seedlings per PMH_0. The study included 13 operators and the average productivity was 143 seedlings per productive machine hours (PMH_0) for the first planting season. For the second planting season, work productivity averaged at 169 seedlings per PMH_0 (Table 1). Variables such as stoniness, stumps, surface obstacles and humus layer had significant impact on the work productivity (Rantala and Laine, 2010). The work productivity decreased when the number of stones and stumps were higher and the humus layer was thicker.

Laine and Rantala (2013) carried out another study on M-planters using six operators with four machines (excavators). They used seedlings of Norway spruce (*Picea abies*). The factors influencing the work productivity in sample plots were identified and included slash, slope, number of surface obstacles and stumps, stoniness and thickness of humus layer. The work productivity of M-planter varied among different operators ranging from 279 seedlings per PMH_0 to 387 seedlings per PMH_0 (Table 1). The productivity averaged at 344 seedlings per PMH_0. The study results confirmed that different operators did not have significant impact on the productivity as all operators were experienced. The quality of planting was acceptable as the planting den-

Figure 1. M-planter based on excavator in Finland (http://www.m-planter.fi/en/M-Planter.html)

Table 1. Summary of productivity studies on mechanical planting

Continent	Country	Variables impacting productivity	Productivity (Seedlings/PMH$_0$)	Reference
Europe	Finland	stoniness, stumps, surface obstacles and humus layer	143-169	Rantala and Laine (2010)
	Finland	slash, slope, number of surface obstacles and stumps, stoniness and thickness of humus layer	279-387	Laine and Rantala (2013)
	Sweden	number of planting heads per planting device	200-475	Errson et al. 2013
America	Brazil	planting spacing	324-355	Guerro et al. 2019

sity was mostly close to 1800 seedlings per hectare (ha), which was higher than the minimum acceptable number of 1600 seedlings per ha based on the Finnish forestry recommendations (Laine and Rantala, 2013).

In Sweden, Errson et al. (2013) indicated that application of two-armed planting machines may require semi-automation, which could provide better control and higher productivity. Two-headed machines (such as M-planters) can plant two seedlings simultaneously, and thus their productivity may be higher than one-headed machines. Errson et al. (2013) developed the simulation models to consider terrain and two-armed planting machines. The study results showed that when four planting heads were mounted pair-wise on two arms, the machine productivity increased. However, the two-armed and four-headed model did not yield higher productivity than single- arm machines. The planting productivity ranged from 200 seedlings per PMH$_0$ to 475 seedlings per PMH$_0$ according to Errson et al. (2013). There are two ways

for loading seedling into planting machines; piece-wise loading or tray-wise loading. Research results from Errson et al. (2014) in Swedish clear-cut areas confirmed that application of tray-wise loading on the Bracke mechanical planter (set up on a medium- sized excavator) can increase work productivity by 8-9% depending on the type of planting machine. Lideskog et al. (2015) developed a new design for the forestry machines, which was a platform to test and validate the autonomy and robotics of a research vehicle platform in forestry that could be equipped with planting arms. One of the ideas presented in that report (Lideskog et al. 2015) was to record the harvested trees and stumps with coordinates to be recognised by the sensors to help avoiding stumps as obstacles during mechanical planting.

Laine (2017) studied the mechanical tree planting to improve its productivity in Finland. He used various independent variables such as work difficulty, operator, worksite, operator experience with machines, operator experience with planting equipment (e.g. M-planter), type of base machine and type of planting device in his mixed linear models in various trials (Rantala, Laine, 2010; Laine, Rantala (2013); Laine, Saarinen, (2014)). From the statistical analysis by Laine (2017), the work difficulty was a significant factor impacting the productivity. Laine's thesis results indicated that for spot mounding the productivity ranged from 0.90 ha per PMH_0 (for Naarva planter based on 15 t excavator (Saarinen, 2006)) to 0.17 ha per PMH_0 (for Bracke M.26 based on 14 t forwarder (Saksa et al. 2002, Saarinen, 2006)) [note that the value in seedlings per PMH_0 was not reported]. The planting productivity for Bracke P.11a based on 15 t excavator averaged at 150 seedlings per PMH_0 (Arnkil, 1997), while for M-planter based on similar size of excavators, the productivity was 151 seedlings per PMH_0.

America

According to the review conducted by Ramantswana et al. (2020), in Brazil the mechanical planting has been applied. One of the planting technologies was MTM1000 in eucalypt plantations where seedlings were planted within farrows. There was also a new triple planter such as a semi-autonomous machine that was based on a tractor, which was equipped with a water tank to provide irrigation in addition to planting (Ramantswana et al. 2020). The Swedish-made Bracke P11.a based on an excavator was studied when planting eucalypt seedlings (*Eucalyptus grandis* × *E. urophylla)* in São Paulo state, Brazil (Guerro et al. 2019). The results showed that the productivity was significantly different within the two types of planting space. The average productivity was 355 seedlings per PMH_0 for spacing of 3m × 1m, while the spacing of 3m × 1.5m resulted in lower productivity such as 324 seedlings per PMH_0.

Other regions

Mechanical planters are also used in the other regions of the world. The Proplant planting machines have been manufactured in South Africa to be used for cultivating

Figure 2. Risutec planting machines tested in New South Wales, Australia (https://www.farmweekly.com.au)

the spot, providing spot spray, planting, watering and fertilising the seedlings (www.nqfsa.com). This type of machine (which is based on a six-ton excavator) can mitigate the transplant shock which can result in quick and healthy growth.

In some Australian forest areas, there is no mechanical planting due to the slope and terrain conditions to operate safely, thus some companies, such as Hancock Victorian Plantations (HVP), plant about 7 million trees per year by hand (https://www.hvp.com.au). However, a few forest companies have started trialling mechanical planting in flat and moderately-sloping terrains. Forest Corporation New South Wales tested the Finnish machine Risutec (Figure 2) to replant burnt forests more quickly. Spot cultivation removed the need of site preparation. The Risutec machine performed several tasks in one pass, including cultivation, planting and potential application of water and fertiliser (https://www.farmweekly.com.au). The work productivity details of this trial have not been published. In Table 1 were summarised data on the productivity of some selected international case studies on mechanical planting. Table 1 indicated that the global range of productivity varied from 143 to 475 seedlings per PMH_0.

Conclusions

Rantala and Laine (2010) mentioned that mechanical planting requires experienced and good operators but the whole supply chain of planting should be well managed. According to Laine (2017), the productivity of mechanical planting depends on the machine, environment (such as surfaces obstacles and stoniness) and the operator

experience; however, the size of base machine (which planters were based on) did not have significant impact on planting productivity. Employing skilled operators and selecting a suitable worksite can help increasing work productivity (Laine, 2017). To utilise the mechanical planters effectively, the annual planting capacity should be as high as 130-150 ha (Laine, 2017).

Laine and Rantala (2013) concluded that recovering slash and stumps can help increasing the mechanical planting. Employing highly experienced operators may also assist the reduction of the planting cost. In addition, idling time of machines needs to be minimised in order to reduce the costs. According to Ramantswana et al. (2020), as mechanical planting machines get more widely adopted in different countries their overall efficiency will improve. Ramantswana et al. (2020) also point that one of the threats associated with the mechanical planting are the higher carbon emissions and soil compaction in comparison with the manual planting. Guerra et al. (2019) suggest studying the quality of planting in order to provide additional information for the decision makers to implement mechanical planters in Brazil.

The quality of mechanical planting is close to manual planting; however, it is important that the nurseries provide quality seedlings with the suitable age and size to ensure the success of planting with machines (Laine and Rantala, 2013). Most of the reviewed case studies in this article were based on a small number of observations and the observers might had impacted the productivity of the operators, thus the results should be cautiously interpreted (Laine, 2013).

According Errson (2014) the application of mechanical planting can provide further value such as adding watering and fertilising capabilities that has been implemented when planting eucalypt in China, Indonesia and Brazil. As crane-mounted planting machines have resulted in high survival rates of planted trees, they might be more widely used for clear- cut silvicultural regimes. Furthermore, Errson (2014) predicted that mechanised fill-planting would be more cost effective than the manual planting for selective cutting and retention forestry regimes. Ersson (2014) also suggested that future research can develop a three-headed planting device set up on an excavator and test its silvicultural performance on the rough terrains.

Future solutions for improving machine productivity should also consider reducing mental and physical strains on the mechanical planting operators (Laine, 2017). In order to accelerate the mechanisation, the planting machine concepts should be commercialised. Laine (2017) also suggested that the whole planting chain, from nursery to the planting phase, should be integrated and optimised to reduce the cost and improve the productivity. The other suggestion was to improve the handling and maintenance of the seedlings during transport and temporary storage which could help increasing the productivity of mechanical planting. Laine (2017) mentioned that recovering the harvesting residues and stumps for bioenergy can be useful to help increasing the land areas suitable for mechanical planting (Saarinen, 2006).

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